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# MULTIMEDIA UNIVERSITY

## FINAL EXAMINATION

TRIMESTER 3, 2017/2018

### EEL2216 – CONTROL THEORY

( All sections / Groups )

4 JUNE 2018  
9.00 a.m. – 11.00 a.m.  
( 2 Hours )

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#### INSTRUCTIONS TO STUDENTS

1. This question paper consists of **SIX** pages including cover page with **FOUR** questions only.
2. Answer **ALL** questions and print all your answers in the answer booklet provided.
3. All questions carry equal marks and the distribution of the marks for each question is given.

**Question 1**

- (a) Consider the unity feedback system shown in Figure Q1(a).

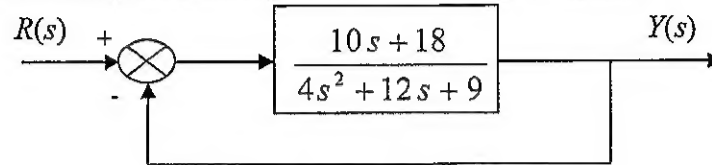


Figure Q1(a)

- (i) Find the zeros and poles of  $F(s) = \frac{10s+18}{4s^2+12s+9}$ . [2 marks]
- (ii) Determine the values of  $A$  and  $B$ , when  $F(s)$  is written in form of  $F(s) = \frac{A}{2s+3} + \frac{B}{(2s+3)^2}$ . [6 marks]
- (iii) Using inverse Laplace transform, determine  $f(t)$ . [3 marks]
- (b) Derive the closed-loop transfer function  $Y(s)/R(s)$  for the block diagram shown in Figure Q1(b) by using the block diagram reduction method. Show your method step by step. [5 marks]

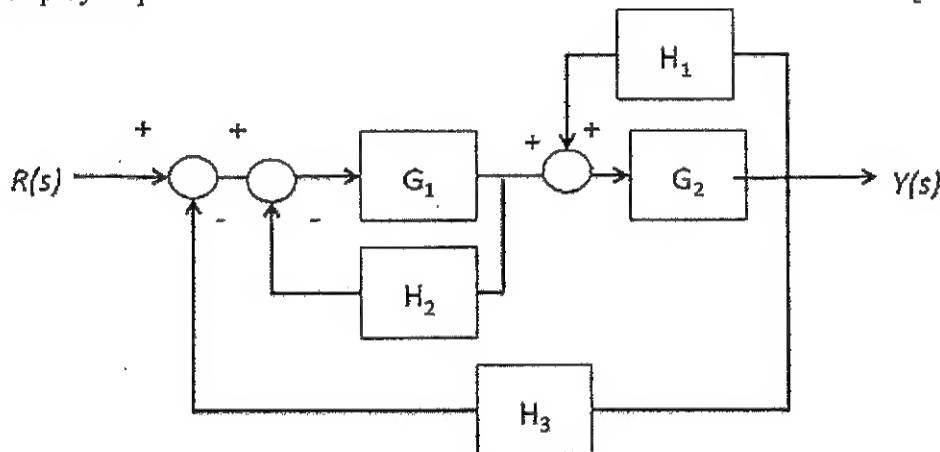


Figure Q1(b)

- (c) Derive the transfer function  $y_5/y_1$  for the signal flow graph as shown in Figure Q1(c) by using Mason's rule. [9 marks]

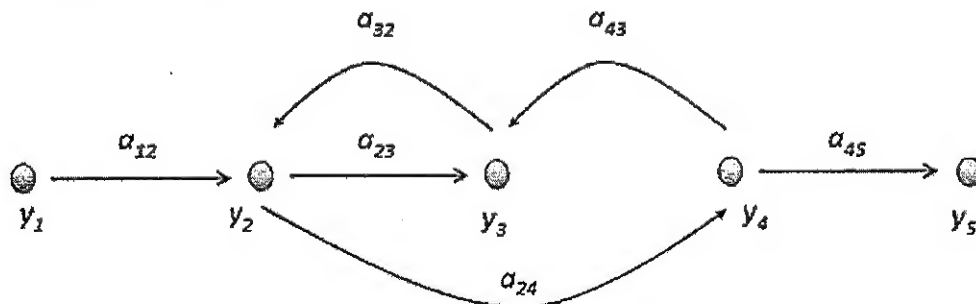


Figure Q1(c)

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**Question 2**

- (a) Briefly explain the Routh-Hurwitz (RH) criterion for the determination of system stability. [3 marks]
- (b) The closed-loop transfer function of a second order system is given below, where  $Y(s)$  is the output while  $R(s)$  is the input:

$$\frac{Y(s)}{R(s)} = \frac{K}{(s + 0.5)(s + \beta) + K}$$

Find  $K$  and  $\beta$  such that the delay time,  $t_d$ , is 5s and rise time,  $t_r$ , is 8s. (Given that  $t_d = \frac{1 + 0.7\zeta}{\omega_n}$  and  $t_r = \frac{0.60 + 2.16\zeta}{\omega_n}$ .  $\zeta$  and  $\omega_n$  are the damping ratio and natural undamped frequency, respectively). [8 marks]

- (c) A negative unity feedback amplifier system has the following loop transfer function:

$$KG(s)H(s) = \frac{K(s + 2)}{(s + 1)(s + 5)(s + 8)}$$

Determine the following:

- (i) The starting and ending points. [2 marks]  
 (ii) The number of branches. [1 mark]  
 (iii) Behaviour at infinity. [2 marks]  
 (iv) Root loci on the real axis. [1 mark]

Given that the break-away point on the real axis is -6.45, sketch the root locus of the system. What is the range of  $K$  for stability? Give your reason. Predict the effect of adding a pole to  $G(s)H(s)$  on the root locus of the system above. [4+4 marks]

**Question 3**

- (a) The forward path transfer function of a unity-feedback control system is given as:

$$G(s) = \frac{24}{(s + 2)(s + 6)}$$

- (i) Analytically calculate the resonance peak,  $M_r$  and its resonant frequency,  $\omega_r$  of the closed-loop system. [5 marks]  
 (ii) What is the relationship between  $M_r$  and damping ratio,  $\zeta$ ? [2 marks]

Continued...

- (b) Consider the following transfer function:

$$G(s)H(s) = \frac{5}{s(s+3)}$$

- (i) List out all the basic factors and their corresponding corner frequencies, magnitudes/slopes and phases. [10 marks]
- (ii) Sketch the Bode asymptotic magnitude and asymptotic phase plots **accurately** on a semi-log paper. [6 marks]
- (iii) Based on part(b)(ii), estimate the phase margin (PM) and its corresponding gain crossover frequency ( $\omega_{gc}$ ). [2 marks]

#### Question 4

- (a) There are various controller/compensator configurations in control system compensation such as cascade compensation and feedback compensation.
  - (i) Draw the configurations for cascade compensation and feedback compensation. [4 marks]
  - (ii) State one advantage of feedback compensation over cascade compensation. [2 marks]
- (b) The unity feedback system shown in Figure Q4 has a controller  $K(s)$  and a plant transfer function  $G(s)$  given by:

$$G(s) = \frac{1}{(s+3)(s+7)}$$

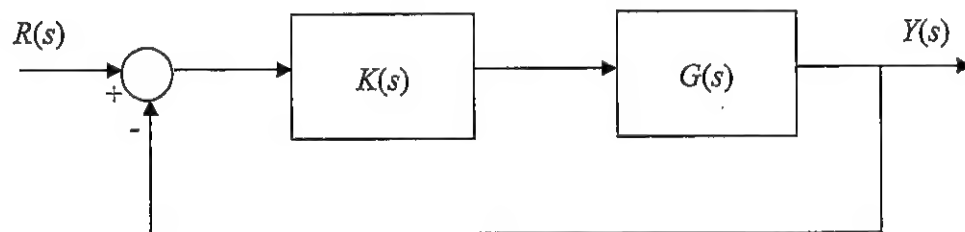


Figure Q4(b)

Design the following:

- (i) A Proportional Derivative (PD) controller,  $K(s) = K_P + K_D s$  such that the damping ratio is 0.85 and the steady-state error of the cascaded system is 5% for a unit step input. [8 marks]
- (ii) A lead compensator controller,  $K(s) = \frac{B(s+z)}{(s+p)}$  if the system have dominant poles at  $s = -7 \pm j20$  and a compensator pole at  $s = -10$  (i.e.  $p = 10$ ). [11 marks]

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## Appendix - Laplace Transform Pairs

$f(t)$	$F(s)$
Unit impulse $\delta(t)$	1
Unit step $1(t)$	$\frac{1}{s}$
$t$	$\frac{1}{s^2}$
$\frac{t^{n-1}}{(n-1)!} \quad (n = 1, 2, 3, \dots)$	$\frac{1}{s^n}$
$t^n \quad (n = 1, 2, 3, \dots)$	$\frac{n!}{s^{n+1}}$
$e^{-at}$	$\frac{1}{s+a}$
$te^{-at}$	$\frac{1}{(s+a)^2}$
$\frac{t^{n-1}}{(n-1)!} e^{-at} \quad (n = 1, 2, 3, \dots)$	$\frac{1}{(s+a)^n}$
$t^n e^{-at} \quad (n = 1, 2, 3, \dots)$	$\frac{n!}{(s+a)^{n+1}}$
$\sin \omega t$	$\frac{\omega}{s^2 + \omega^2}$
$\cos \omega t$	$\frac{s}{s^2 + \omega^2}$
$\sinh \omega t$	$\frac{\omega}{s^2 - \omega^2}$
$\cosh \omega t$	$\frac{s}{s^2 - \omega^2}$
$\frac{1}{a}(1 - e^{-at})$	$\frac{1}{s(s+a)}$
$\frac{1}{b-a}(e^{-at} - e^{-bt})$	$\frac{1}{(s+a)(s+b)}$
$\frac{1}{b-a}(be^{-bt} - ae^{-at})$	$\frac{s}{(s+a)(s+b)}$
$\frac{1}{ab} \left[ 1 + \frac{1}{a-b}(be^{-at} - ae^{-bt}) \right]$	$\frac{1}{s(s+a)(s+b)}$

Continued...

## Appendix - Laplace Transform Pairs (continued)

$\frac{1}{a^2}(1 - e^{-at} - ate^{-at})$	$\frac{1}{s(s+a)^2}$
$\frac{1}{a^2}(at - 1 + e^{-at})$	$\frac{1}{s^2(s+a)}$
$e^{-at} \sin \omega t$	$\frac{\omega}{(s+a)^2 + \omega^2}$
$e^{-at} \cos \omega t$	$\frac{s+a}{(s+a)^2 + \omega^2}$
$\frac{\omega_n}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin \omega_n \sqrt{1-\zeta^2} t$	$\frac{\omega_n^2}{s^2 + 2\zeta\omega_n s + \omega_n^2}$
$-\frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_n \sqrt{1-\zeta^2} t - \phi)$ $\phi = \tan^{-1} \frac{\sqrt{1-\zeta^2}}{\zeta}$	$\frac{s}{s^2 + 2\zeta\omega_n s + \omega_n^2}$
$1 - \frac{1}{\sqrt{1-\zeta^2}} e^{-\zeta\omega_n t} \sin(\omega_n \sqrt{1-\zeta^2} t + \phi)$ $\phi = \tan^{-1} \frac{\sqrt{1-\zeta^2}}{\zeta}$	$\frac{\omega_n^2}{s(s^2 + 2\zeta\omega_n s + \omega_n^2)}$
$1 - \cos \omega t$	$\frac{\omega^2}{s(s^2 + \omega^2)}$
$\omega t - \sin \omega t$	$\frac{\omega^3}{s^2(s^2 + \omega^2)}$
$\sin \omega t - \omega t \cos \omega t$	$\frac{2\omega^3}{(s^2 + \omega^2)^2}$
$\frac{1}{2\omega} t \sin \omega t$	$\frac{s}{(s^2 + \omega^2)^2}$
$t \cos \omega t$	$\frac{s^2 - \omega^2}{(s^2 + \omega^2)^2}$
$\frac{1}{\omega_2^2 - \omega_1^2} (\cos \omega_1 t - \cos \omega_2 t) \quad (\omega_1^2 \neq \omega_2^2)$	$\frac{s}{(s^2 + \omega_1^2)(s^2 + \omega_2^2)}$
$\frac{1}{2\omega} (\sin \omega t + \omega t \cos \omega t)$	$\frac{s^2}{(s^2 + \omega^2)^2}$

End of Paper

